

SUBCOMMITTEE ON SPACE AND AERONAUTICS  
COMMITTEE ON SCIENCE  
U.S. HOUSE OF REPRESENTATIVES  
HEARING CHARTER

*The National Academy of Sciences' Decadal Plan for Aeronautics:  
A Blueprint for NASA?*

Tuesday, July 18, 2006  
2:00 pm – 4:00 pm  
2318 Rayburn House Office Building

**Purpose**

On Tuesday, July 18, 2006, at 2:00 p.m., the Space and Aeronautics Subcommittee will hold the first of two hearings on NASA's efforts to refocus and reshape its civil aeronautics research and development program. The hearing will take testimony from witnesses representing industry, academia, and the National Academies. At the second hearing planned for September (date TBD), Dr. Lisa Porter, NASA Associate Administrator for Aeronautics Research Mission Directorate, will testify.

Together, these hearings will review the results of two reports recently released by the National Research Council (NRC) on NASA's civil aeronautics R&D program. The first, *Aeronautics Innovation: NASA's Challenges and Opportunities*, published in early May, provides recommendations on tools, techniques, and management practices to facilitate and accelerate innovation in NASA's aeronautics programs. The second, *Decadal Survey of Civil Aeronautics*, published in early June, provides a specific set of priority projects to be undertaken in the next 10 years. Over the years, similar surveys in NASA's science programs have been a significant factor in setting program and budget priorities. The aeronautics decadal survey is the first time such a comprehensive survey has been done on aeronautics.

The hearings will also help set the stage for the development of an overarching national aeronautics policy, due to be released at the end of this year. Congress directed the Administration, in last year's NASA Authorization bill, to develop a national aeronautics policy to guide federal investments in aeronautics research because of concerns over the downward trend over the last decade in funding for NASA's aeronautics program and the changing goals and priorities.

**Witnesses**

**Dr. Paul Kaminski** is Chairman of the National Research Council's Steering Committee that produced the *Decadal Survey of Civil Aeronautics* (released in June 2006). He is the Chairman and CEO of Technovation, Inc. and served as the Undersecretary of Defense for Acquisition and Technology in the Clinton Administration.

**Dr. Steven Merrill** is Executive Director of the National Research Council's Board on Science, Technology, and Economic Policy. He managed the NRC Committee that produced *Aeronautics Innovation: NASA's Challenges and Opportunities* (released in May 2006).

**Dr. Michael Romanowski** is Vice President for Civil Aviation, Aerospace Industries Association.

**Dr. Parviz Moin** is a Professor of Mechanical Engineering at Stanford University and director of the Institute for Computational and Mathematical Engineering, the Center for Turbulence Research, and the ASCI Center for Integrated Turbulence Simulations. He is a fellow of the American Physical Society.

### **Overarching Questions**

1. What should the goals, strategies and activities be for NASA's aeronautics research and development program?
2. What should NASA be doing to ensure that its research is relevant to the long-term needs of industry and is used by industry? What should NASA be doing to help keep the academic research enterprise healthy and to ensure an adequate supply of aeronautics engineers and researchers?

### **Reshaping NASA's Aeronautics Research Program**

Early this year Dr. Lisa Porter, who was appointed as NASA's Associate Administrator for Aeronautics Research Mission Directorate (ARMD) in October 2005, announced a major restructuring of the aeronautics research program. The new goals are to re-establish ARMD's core competencies in subsonic, supersonic and hypersonic flight; to focus research in areas that are appropriate to ARMD's unique capabilities; and to directly address the fundamental research needs of the Next Generation Air Transportation System (NGATS), a partnership with the Federal Aviation Administration (FAA) and other agencies. Dr. Porter's "back-to-basics" approach puts greater emphasis on fundamental research and less emphasis on technology demonstrations.

Prior to Dr. Porter's arrival, ARMD had three major programs: Vehicle Systems; Aviation Safety and Security; and Airspace Systems. Vehicle Systems was the largest and included plans to pursue four major technology demonstration flight projects: subsonic noise reduction; sonic boom reduction; zero emissions aircraft; and a high-altitude, long-endurance unmanned air vehicle. All the demonstration projects have been cancelled.

Following the restructuring, Vehicle Systems was renamed Fundamental Aeronautics; Aviation Safety and Security was renamed Aviation Safety; and Airspace Systems remained unchanged. A fourth program line, Aeronautics Test Program, was established to ensure long-term stewardship of eleven NASA aeronautics test facilities (wind tunnels

and engine test stands) located at the Ames Research Center, Langley Research Center, and Glenn Research Center, which are considered to be critical national assets.

### **National Research Council Reports**

#### ***Aeronautics Innovation: NASA's Challenges and Opportunities***

In mid-2004, NASA asked the National Academies' Board on Science, Technology, and Economic Policy (STEP) to recommend tools, techniques, and practices that might facilitate and accelerate innovation in NASA's aeronautics research program. To carry out this task, the NRC created an ad hoc committee – known as the Committee on Innovation Models for Aeronautics Technologies – of academic experts in technology management and public administration.

In carrying out their task, the committee said it was struck by the growing discrepancy between the goals and objectives of NASA's aeronautics research program and the resources available to it. While the committee developed a roster of recommendations to improve management practices, it clearly indicated that the first order of business should be to bridge the gap between the stated goals and budget realities. Specifically, the report said:

The committee concluded that NASA's aeronautics program faces an overriding management challenge: a lack of national consensus about the federal government's role in civilian aviation generally and NASA's role in aviation technology development in particular. On the one hand, the community of industry, academic, and other stakeholders and experts support an expansive public research and development program with NASA playing a lead role. On the other hand, successive administrations and sessions of Congress have over the past seven or eight years reduced NASA's aeronautics budget without articulating how the program should be scaled back. In these circumstances, NASA has tried to maintain an expansive program by spreading diminishing resources across existing research establishments and many objectives and projects – too many to ensure their effectiveness and the application of their results.

The committee made numerous recommendations, summarized below, regarding technology transition planning, and personnel and financial management practices, to improve innovation in the program. Some of the recommendations, such as establishing a national aeronautics policy, were already in progress at the time the report was released.

#### **Summary of Key Recommendations:**

- Congress and the Executive Branch should engage in a dialog on the goals for civil aviation (i.e., establish a national aeronautics policy).
- NASA must translate the national aeronautics policy into a balanced portfolio of programs that are in alignment with its resources.

- NASA should set decision criteria to evaluate progress and force accountability to all involved.
- NASA should cultivate close relationships and regularly involve external partners in all phases of an activity, including technology transition (hand-off).
- NASA should work aggressively to solidify its reputation as a trustworthy, reliable partner.
- NASA should implement more flexible personnel policies to increase collaboration and innovative thinking.
- NASA should expand the use of prizes to offer high-profile aeronautics prizes to generate increased participation and public interest.
- NASA should modify full-cost pricing policies for use of facilities, with costs more closely aligned with marginal costs.
- NASA should explore the use of working capital fund structures, such as used in the Defense Department, as well as funding pools and contingency accounts to provide stability and flexibility.

A complete set of the report's recommendations appears in the Appendix. A full copy of the report appears at the website: <http://darwin.nap.edu/books/0309101883/html>

***Decadal Survey of Civil Aeronautics: Foundation for the Future***

In 2005, NASA contracted with the NRC, under the auspices of the its Aeronautics and Space Engineering Board (ASEB), to develop a consensus document representing the external (industry and academia) community's views about what NASA's aeronautics research priorities ought to be. The effort was led by a Steering Committee chaired by Dr. Paul Kaminski and had five panels, (Aerodynamics and Aeroacoustics; Propulsion and Power; Materials and Structures; Dynamics, Navigation and Control, and Avionics; and Intelligent and Autonomous Systems), that drew on a group of 85 aeronautics experts from academia and industry. This was the first decadal survey ever produced for NASA's aeronautics program<sup>1</sup>. Their report was released on June 5, 2006. A copy of their recommendations appears in the Appendix; a copy of the full report can be found at: <http://www.nap.edu/catalog/11664.html>

Decadal surveys are designed to provide strategic guidance to NASA. With respect to the space sciences programs, NASA has over the years relied heavily on survey recommendations to shape the scope, content and timing of NASA's missions.

The report lays out five key areas for research: aerodynamics and aeroacoustics; propulsion and power; materials and structures; dynamics, navigation and control, and avionics; and intelligent and autonomous systems, operations and decision making, human integrated systems, networking and communications. Under each of those areas, the report lays out a prioritized list of "challenges" to address – 51 in all. The report also lays out five "themes" that cut across all the research areas.

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<sup>1</sup> The NRC has written decadal surveys for NASA's space sciences programs for more than 50 years. As the name implies, these studies are expected to be updated every ten years.

Summary of Key Recommendations (complete list is in the appendix):

- NASA should use the 51 Challenges as the foundation for its aeronautics research program over the next decade.
- A high priority should be placed on establishing and maintaining a *stable* aeronautics research program.
- NASA should use the five Common Themes (see appendix for details) to make the most efficient use of research funding.
- NASA should support research to develop practical certification standards for new technologies.
- The U.S. government should align organizations and develop techniques to improve change management to assure a safe and cost-effective transition to the air transportation system of the future.
- NASA should ensure that it involves universities and industry in its planning, and develop a more balanced funding allocation between “in-house” and external organizations.
- NASA should consult with non-NASA stakeholders, such as in the Defense Department and FAA, on the most effective use of facilities and tools applicable to aeronautics research.
- The U.S. government should conduct a high-level review of organizational options for ensuring U.S. leadership in civil aeronautics.

**Key Issues**

**What goals for aeronautics research are realistic given the projected budget?** For the last several years NASA’s budget for the Aeronautics Research Mission Directorate (ARMD) has been declining both in dollars, and as a fraction of NASA’s overall budget. Specifically, in FY04 NASA’s budget for aeronautics was over \$1 billion. NASA’s aeronautics budget for FY06 was \$884 million, and NASA’s request for FY07 is \$724 million. (The House-passed appropriation for FY07 provides an additional \$100 million above that.) If this year’s request is enacted, NASA’s aeronautics budget will have sustained a 32 percent cut in three years, even though NASA’s budget as a whole will have increased by 9 percent over the same period. While ARMD’s budget is projected to be flat over the next five years, it’s burdened with a disproportionate share of infrastructure costs (e.g., wind tunnels and test stands). At issue is how many of the Decadal Survey’s recommendations can NASA realistically accomplish? What is the appropriate balance between goals and budget?

**Does NASA’s research portfolio strike the right balance between basic research and work that may be of more direct and immediate relevance to industry?** In the past year, NASA has reoriented its portfolio more toward fundamental research, arguing that that is an appropriate federal role and that the results of such research will increase knowledge in a way that will allow significant advances in aviation. But the NRC’s *Aeronautics Innovation* study argued that NASA should pursue a limited number of research projects to a high enough technology maturity level so that industry would be

willing to adopt the technology. Otherwise, it said, NASA may in time lose its relevance to industry.

### **Should NASA implement the priorities of the Decadal Survey of Civil Aeronautics?**

NASA is still putting together specific project plans to carry out its research agenda. The Decadal Survey provides technical objectives and milestones for each of the 51 “Challenges,” but without a similar level of detail on NASA’s plans it is difficult to compare the two. One point of the hearing, and the follow-up hearing with NASA in the fall, will be to get both NASA and the Academy panel to provide more details and an assessment of their respective research agendas so they can be compared and evaluated.

**Has NASA struck the appropriate balance between in-house work and external work?** The NRC Decadal Survey states that NASA must create a more balanced split in the allocation of funding between in-house research performed by NASA engineers and external research performed by industry and academia. NASA’s budget documents appear to allocate 93 percent of funds for in-house work and 7 percent for external work. However, NASA argues this breakout is closer to 75 percent in-house and 25 percent external. This is because NASA’s numbers include funds for service contracts that are not focused on research.

### **FY07 Aeronautics Budget Highlights**

For FY06, ARMD’s appropriated budget is \$884.1 million. NASA is proposing in FY07 to spend \$724.4 million on aeronautics, a cut of \$160 million from this year (an 18 percent reduction).

ARMD’s four programs are listed in the table below. Airspace Systems supports the Joint Planning and Development Office’s (JPDO) efforts to develop and deploy the Next Generation Air Transportation System (NGATS). (The Subcommittee held a hearing on the JPDO earlier this year.) The Aeronautics Test Program is new for FY07 and pays a portion of maintenance and operational costs for 11 nationally important wind-tunnel test facilities owned by NASA.

### **FY07 NASA Aeronautics Funding Request (\$=millions)**

	FY04 Actual	FY05 Actual	FY06 Actual	FY07 Budget	FY08 Runout	FY09 Runout	FY10 Runout	FY11 Runout
Aviation Safety	183.1	183.0	148.4	102.2	102.1	116.1	119.9	119.8
Airspace Systems	232.3	148.8	173.9	120.0	124.0	105.4	91.1	89.4
Fundamental Aeronautics	641.4	630.2	561.7	447.2	449.3	452.9	452.5	452.8
Aeronautics Test Program				55.0	56.4	58.0	59.2	60.7
<b>TOTAL</b>	<b>\$1056.8</b>	<b>\$962.0</b>	<b>\$884.0</b>	<b>\$724.4</b>	<b>\$731.8</b>	<b>\$732.4</b>	<b>\$722.7</b>	<b>\$722.7</b>
ARMD share of agency budget (%)	<b>6.9%</b>	<b>5.7%</b>	<b>5.3%</b>	<b>4.3%</b>	<b>4.2%</b>	<b>4.2%</b>	<b>4.0%</b>	<b>3.9%</b>

ARMD carries a disproportionate share of the agency's personnel and infrastructure costs, largely due to the agency's investment in test facilities at NASA's three aeronautics research centers: Langley Research Center (VA); Glenn Research Center (OH); and Dryden Flight Research Center (CA). In addition, ARMD employs 23 percent of the agency's workforce.

#### *Aviation Safety*

Prior to the reorganization early this year, this program was called "Aviation Safety and Security." NASA determined that security issues were not its responsibility (it resides within the Department of Homeland Security), thus that portion of its research portfolio has been transferred or dropped.

The Aviation Safety program's goal is improving the safety of current and future aircraft operating in our nation's airspace. The research focus is on the way aircraft are designed, built, operated, and maintained. Projects include Integrated Vehicle Health Management; Integrated Intelligent Flight Deck; Integrated Resilient Aircraft Control; and Aircraft Aging and Durability. For FY07, ARMD is proposing to spend \$102 million, a 31 percent reduction compared to this year's \$148 million appropriation.

#### *Airspace Systems*

The goal of the Airspace Systems program is to research and develop tools and operational concepts to make our nation's Air Traffic Management system safer, more efficient and secure, and capable of handling larger numbers of aircraft. Airspace Systems performs long-term R&D research for the Federal Aviation Administration. Following creation of the JPDO – as required by Congress in the *Vision 100* legislation, now Public Law 108-176 – Airspace Systems was aligned to support the work of the JPDO to design and deploy the Next Generation Air Transportation System. For FY07, ARMD is proposing to spend \$120 million, a 31 percent reduction compared to this year's \$174 million appropriation.

#### *Fundamental Aeronautics*

For FY07 NASA proposed a reorganization, a reduction in funding, restoration of hypersonics and rotorcraft research, and a renaming of the program. ARMD is proposing to spend \$447.2 million, a 20 percent reduction compared to this year's \$561.7 million appropriation.

The goal of Fundamental Aeronautics is to provide long-term investment in research to support and sustain expert competency in core areas of aeronautics technology. Four research thrusts have been established: Hypersonics; Subsonic – Rotary Wing; Subsonic – Fixed Wing; and Supersonics. To achieve these goals, ARMD plans to focus on advanced tools such as new computational- and physics-based software modeling and simulation programs and capabilities that will enable whole new classes of aircraft that not only meet the noise and emissions requirements of the future, but also provide fast and efficient flight.

### *Aeronautics Test Program*

The Aeronautics Test Program (ATP) is new and part of a larger NASA program called Shared Capabilities Asset Program (S-CAP). ATP's purpose is to ensure the strategic availability of a minimum, critical suite of wind tunnels/ground test facilities which are necessary to meet the mission of ARMD, NASA, and national needs. ATP funds a portion of the fixed operating costs of eleven wind tunnels/ground test facilities at Ames Research Center, Langley Research Center, and Glenn Research Center.

The RAND Corporation conducted a study for NASA that recommended that NASA ensure the continued operation of 29 of its 31 wind tunnels. RAND estimated the annual operating cost of all 31 tunnels to be \$125-\$130 million and concluded that while some of the tunnels were not being utilized at a high rate, they offered capabilities that could be needed in the future and would be hard to replicate if shut down. ATP is NASA's response to these concerns.

Last year's NASA Authorization bill included a provision directing the Office of Science and Technology Policy to report to Congress on the nation's long-term strategic needs for aeronautics test facilities. It also bars NASA from closing any of its test facilities until the report is delivered, and requires the NASA Administrator to certify to Congress that proposed closures will have no adverse impact. The report has not yet been delivered.

For FY07, NASA is proposing a budget of \$55 million for ATP. This figure does not represent all of NASA's investment in wind tunnels/ground test facilities, but only for 11 tunnels deemed to be under-utilized and of critical national importance.

### *National Aeronautics Policy*

The NASA Authorization Bill included a provision directing the President to develop a national policy to guide federal aeronautics research and development through 2020. The bill specified that the policy include national goals for aeronautics R&D and describe the roles and responsibilities for each federal agency that will carry it out. The policy is due at the end of this calendar year.

NASA and the White House Office of Science and Technology Policy, working through the National Science and Technology Council, are leading the policy's development.

## **Background**

### *NASA's Aeronautics Research*

NASA's roots in aeronautics research reach back almost 90 years – to 1917 – when the National Advisory Committee on Aeronautics was formed. Responding to the launch of Sputnik almost 40 years later, in 1958 Congress passed legislation changing the agency's name to the National Aeronautics and Space Administration and broadening its mission to include human spaceflight and space exploration.



NASA-developed technology is found in virtually every airplane flying today. Examples include the high-bypass turbine engine that provides much greater fuel efficiency and lower noise emissions than original 1960's-era jet engines; "fly-by-wire" control systems that use computers and wires instead of heavy, maintenance-intensive hydraulics systems to control an airplane's rudder and wing flaps; flight management systems such as the "black boxes" that continuously monitor an aircraft's engines, speed, location, and other critical parameters; and advanced composites made out of materials such as graphite and epoxy that can be used to replace heavier and more maintenance-intensive aluminum alloy structures. The Boeing 787, now under development, will be the first large civil aircraft to use composite materials in its fuselage.

### *The U.S. Aircraft Industry*

The domestic aeronautics industry has changed substantially over the last ten to fifteen years through consolidations. Today there is only one manufacturer of large civil aircraft, Boeing, and just two turbine engine manufacturers for large civil aircraft, General Electric and Pratt & Whitney. The U.S. has no domestic regional jet manufacturers, the fastest growing segment in civil aviation; most are made in Canada and Brazil. The business jet and general aviation aircraft industry have a good number of domestic producers.

Boeing is this country's largest exporter of manufactured products (based on dollar value), and draws on thousands of suppliers whose products are found in each jet. Airbus,<sup>2</sup> a European company, had overtaken Boeing in sales earlier this decade, but Boeing has since regained the lead, and Airbus has fallen behind schedule in producing its new A380 aircraft, a "super jumbo" that would be the world's largest passenger-carrying aircraft (it can seat over 800 in a single-class layout). The A380's first commercial delivery is now scheduled for late this year.

Earlier this decade, the European Union (EU) identified aeronautics as part of a continent-wide industrial strategy. The EU produced a research program document, "*Aeronautics 2020*," that explicitly stated the objective of having Europe become the world's leading supplier of aeronautics goods and services and achieving parity with Boeing. The EU also has set a goal of taking a leadership role designing and producing the next generation air traffic management services.

### *National Institute of Aerospace*

In April 2005, the National Institute of Aerospace<sup>3</sup> produced a report titled *Responding to the Call: Aviation Plan for American Leadership* that included an exhaustive list of research projects and activities that should be pursued by NASA if our government were intent on revitalizing the capabilities and products of the U.S. aerospace industry. The report recommended that ARMD's budget be increased by an average of \$885 million over

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<sup>2</sup> Airbus began over 30 years ago as a government-created and owned entity with direct investment by the British, French, Spanish, and German governments. It has since been spun off as a private company owned by EADS and BAE systems, both European based conglomerates.

<sup>3</sup> The National Institute of Aerospace is a non-profit research and graduate education institute created to conduct leading-edge aerospace and atmospheric research. It was formed by a consortium of research universities and is located at the Langley Research Center.

each of the next five years to support their research agenda. A copy of the full report can be found at: <http://www.nianet.org/nianews/AviationPlan.php>

### **Witness Questions**

In their letters of invitation, the witnesses were asked to address the following questions:

Dr. Paul Kaminski, National Research Council (ASEB): Please briefly describe the results of the Decadal Survey and answer the following questions:

1. How would you assess the Aeronautics Research Mission Directorate's (ARMD) program goals and strategies? Given the resources currently allocated to it, is ARMD properly structured, and is it pursuing the right lines of research? Is the balance between in-house and out-of-house research appropriate?
2. Of the 51 research and technology challenges identified in the report, what do you consider to be the top three and why?

Dr. Steven Merrill, National Research Council (STEP): Please briefly describe the conclusions and recommendations of your report and address the following questions:

1. How would you assess the Aeronautics Research Mission Directorate's (ARMD) program goals and strategies? Is NASA's emphasis on foundational research appropriate? Given the resources currently allocated to it, is ARMD properly structured, and is it pursuing the right lines of research?
2. In a constrained budget environment, how should NASA best balance: (1) research conducted in-house versus contracting with outside entities; and (2) near-term research versus research for long-term, high-risk technologies? How can NASA preserve a federal cadre of aeronautics experts and capabilities while also collaborating with academia and industry?

Dr. Michael Romanowski, Vice President, Aerospace Industries Association

1. How would you assess the Aeronautics Research Mission Directorate's program goals and strategies? Is NASA's emphasis on foundational research appropriate? Given the resources currently allocated to it, is ARMD properly structured, and is it pursuing the right lines of research?
2. What should NASA be doing to ensure that its research is relevant to the long-term needs of industry and is used by industry? What should NASA be doing to help keep the academic research enterprise healthy and to ensure an adequate supply of aeronautics engineers and researchers?
3. What is your reaction to the conclusions and recommendations of the Decadal Survey?

Dr. Parviz Moin, Professor of Mechanical Engineering, Stanford University

1. How would you assess the Aeronautics Research Mission Directorate's (ARMD) program goals and strategies? Is NASA's emphasis on foundational research appropriate? Given the resources currently allocated to it, is ARMD properly structured, and is it pursuing the right lines of research?
2. What are the major technological and competitive challenges facing the civil aeronautics industry over the next ten to fifteen years, and how well does the Aeronautics Research Mission Directorate's program attempt to address them?
3. What advantages can be gained by having NASA increase its emphasis on computational- and physics-based modeling? Why should NASA be pursuing this technology? Does NASA have the workforce and facilities to conduct this research?
4. What has been the experience, of late, with respect universities recruiting students into post-graduate aeronautics-related research programs?

## Appendix A

*Aeronautics Innovation: NASA's Challenges and Opportunities*  
National Research Council – Board on Science, Technology, and Economic Policy  
Published May 2006  
Report Website: <http://darwin.nap.edu/books/0309101883/html>

### Recommendations –

Recommendation 1: Congress and the executive branch should engage in a dialogue to articulate national goals in civil aviation and the corresponding public sector roles. The government's role is likely to differ among (1) pursuit of fundamental understanding and yielding scientific and engineering results available to all; (2) pursuit of quasi-public goods such as safety, efficient management, and environmental enhancements; (3) development of improved commercial and general aviation aircraft that are successful in domestic and international markets; and (4) development of advanced aeronautics technologies for which there are currently no providers in prospect. The traditional market failure rationale for government intervention varies considerably among these categories and even within a category over time (depending, for example, on the degree of private competition).

Recommendation 2: ARMD's first order of business in promoting aeronautics innovation is to translate a national aeronautics policy into a strategic or mission focus that is in better alignment with the resources available to it- its budget, its personnel, and its technical capabilities. This, in turn, should lead to a prioritization of programs and projects involving the research centers, external grantees, and contractors. Clearly, the result may be a reduced mission scope and portfolio but one with greater impact on innovation in air transportation.

Recommendation 3-A: Conceive of R&D activities as a cohesive and strategically balanced portfolio of projects and competencies closely aligned with mission and stakeholder needs.

Recommendation 3-B: Graphical illustrations of the portfolio are particularly useful tools for fostering communication and discussion and identifying and resolving disagreements, both internally among managers and in engaging external stakeholders and customers.

Recommendation 3-C: Use decision processes, sometimes referred to as decision gate processes, at predetermined points to establish common expectations among customers, leaders, and the technical team throughout the development process, to clarify goals, schedules, deliverables, concrete target performance metrics, and review templates and to set decision criteria and force accountability of all constituents involved.

Recommendation 3-D: Pursue a portfolio "balanced between near term needs, driven by market forces, and longer-term investments required to achieve transformational national capabilities."

Recommendation 3-E: NASA should continue to undertake core competency reviews and explicitly include aeronautics among the highest priority core competencies. Within aeronautics, the ranking of competencies should take into account world leadership in technology, public additive value, and skills enabling partnerships and transitioning processes.

Recommendation 4-A: ARMD should implement and explicitly regularize for all projects organization-wide series of management tools aimed at fostering technology transition to users.

Recommendation 4-B: ARMD should cultivate close relationships with external partners, engaging them very early in jointly conceptualizing, planning, and prioritizing all R&D activities and sustaining regular involvement through the implementation phase.

Recommendation 4-C: ARMD should work aggressively to solidify its reputation as a trustworthy, reliable partner.

Recommendation 4-D: JPDO may be a model for future ARMD technology management decision making through close external collaboration, with joint recommendations guiding ARMD portfolio planning.

Recommendation 4-E: Documented planning for technology transition (hand-off) to external stakeholders should be a universal managerial practice for all ARMD R&D projects and integral to the portfolio planning and prioritizing process.

Recommendation 4-F: The variety of technologies and the diversity of stakeholder capabilities require increased ARMD flexibility and variability with regard to project time horizons and technology readiness levels.

Recommendation 5-A: ARMD should implement more flexible personnel practices, increase incentives for creativity, and actively manage existing constraints on staffing decision making to minimize their innovation-inhibiting effects.

Recommendation 5-B: ARMD should increase rotation and seconding of personnel to and from its several research centers and its external partners as tools for enhancing staffing and competency flexibility, fostering the early engagement of partners, and facilitating technology transfer.

Recommendation 5-C: NASA should foster external customer contact early in and throughout the careers of ARMD technical personnel.

Recommendation 5-D: ARMD should pilot test a dual track, pay-for-performance program similar to that in place at the Air Force Research Laboratory.

Recommendation 5-E: ARMD should allow R&D personnel some fraction of their time for free thinking and encourage its use by organizing regular employee idea fairs that attract external stakeholders.

Recommendation 5-F: NASA should expand its Centennial Challenges program to offer high-profile aeronautics prizes of a magnitude sufficient to generate considerable participation and public attention.

Recommendation 6-A: NASA should modify full-cost pricing for ARMD facilities use, with charges more closely aligned with marginal costs.

Recommendation 6-B: ARMD should work with OMB and Congress to establish separate centrally funded budget lines for national infrastructure and facilities management.

Recommendation 6-C: Because midstream changes are the nature of leading edge R&D, ARMD should achieve greater budget and milestone flexibility through centrally funded pools and contingency accounts.

Recommendation 6-D: ARMD should explore establishing Working Capital Fund structures for wind tunnels and aeronautics R&D services.

Recommendation 6-E: ARMD should negotiate with congressional sponsors and earmark recipients to align mandated activities better with established programs and should assign the projects to a separate budget account and management area.



TABLE ES-1 Fifty-one Highest Priority Research and Technology Challenges for NASA Aeronautics, Prioritized by R&T Area

A Aerodynamics and Aeroacoustics	B Propulsion and Power	C Materials and Structures	D Dynamics, Navigation, and Control, and Avionics	E Intelligent and Autonomous Systems, Operations and Decision Making, Human Integrated Systems, Networking and Communications
<p>A1 Integrated system performance through novel propulsion-airframe integration</p> <p>A2 Aerodynamic performance improvement through transition, boundary layer, and separation control</p> <p>A3 Novel aerodynamic configurations that enable high performance and/or flexible multi-mission aircraft</p> <p>A4a Aerodynamic designs and flow control schemes to reduce aircraft and rotor noise</p> <p>A4b Accuracy of prediction of aerodynamic performance of complex 3D configurations, including improved boundary layer transition and turbulence models and associated design tools</p> <p>A6 Aerodynamics robust to atmospheric disturbances and adverse weather conditions, including icing</p> <p>A7a Aerodynamic configurations to leverage advantages of formation flying</p> <p>A7b Accuracy of wake vortex prediction, and vortex detection and mitigation techniques</p> <p>A9 Aerodynamic performance for V/STOL and ESTOL, including adequate control power</p> <p>A10 Techniques for reducing/mitigating sonic boom through novel aircraft shaping</p> <p>A11 Robust and efficient multidisciplinary design tools</p>	<p>B1a Quiet propulsion systems</p> <p>B1b Ultraclean gas turbine combustors to reduce gaseous and particulate emissions in all flight segments</p> <p>B3 Intelligent engines and mechanical power systems capable of self-diagnosis and reconfiguration between shop visits</p> <p>B4 Improved propulsion system fuel economy</p> <p>B5 Propulsion systems for short takeoff and vertical lift</p> <p>B6a Variable-cycle engines to expand the operating envelope</p> <p>B6b Integrated power and thermal management systems</p> <p>B8 Propulsion systems for supersonic flight</p> <p>B9 High-reliability, high-performance, and high-power-density aircraft electric power systems</p> <p>B10 Combined-cycle hypersonic propulsion systems with mode transition</p>	<p>C1 Integrated vehicle health management</p> <p>C2 Adaptive materials and morphing structures</p> <p>C3 Multidisciplinary analysis, design, and optimization</p> <p>C4 Next-generation polymers and composites</p> <p>C5 Noise prediction and suppression</p> <p>C6a Innovative high-temperature metals and environmental coatings</p> <p>C6b Innovative load suppression, and vibration and aeromechanical stability control</p> <p>C8 Structural innovations for high-speed rotorcraft</p> <p>C9 High-temperature ceramics and coatings</p> <p>C10 Multifunctional materials</p>	<p>D1 Advanced guidance systems</p> <p>D2 Distributed decision making, decision making under uncertainty, and flight path planning and prediction</p> <p>D3 Aerodynamics and vehicle dynamics via closed-loop flow control</p> <p>D4 Intelligent and adaptive flight control techniques</p> <p>D5 Fault tolerant and integrated vehicle health management systems</p> <p>D6 Improved onboard weather systems and tools</p> <p>D7 Advanced communication, navigation, and surveillance technology</p> <p>D8 Human-machine integration</p> <p>D9 Synthetic and enhanced vision systems</p> <p>D10 Safe operation of unmanned air vehicles in the national airspace</p>	<p>E1 Methodologies, tools, and simulation and modeling capabilities to design and evaluate complex interactive systems</p> <p>E2 New concepts and methods of separating, spacing, and sequencing aircraft</p> <p>E3 Appropriate roles of humans and automated systems for separation assurance, including the feasibility and merits of highly automated separation assurance systems</p> <p>E4 Affordable new sensors, system technologies, and procedures to improve the prediction and measurement of wake turbulence</p> <p>E5 Interfaces that ensure effective information sharing and coordination among ground-based and airborne human and machine agents</p> <p>E6 Vulnerability analysis as an integral element in the architecture design and simulations of the air transportation system</p> <p>E7 Adaptive ATM techniques to minimize the impact of weather by taking better advantage of improved probabilistic forecasts</p> <p>E8a Transparent and collaborative decision support systems</p> <p>E8b Using operational and maintenance data to assess leading indicators of safety</p> <p>E8c Interfaces and procedures that support human operators in effective task and attention management</p>

**BOX ES-1 Recommendations to Achieve Strategic Objectives for Civil Aeronautics Research and Technology**

1. NASA should use the 51 Challenges listed in Table ES-1 as the foundation for the future of NASA's civil aeronautics research program during the next decade.
2. The U.S. government should place a high priority on establishing a *stable* aeronautics R&T plan, with the expectation that the plan will receive sustained funding for a decade or more, as necessary, for activities that are demonstrating satisfactory progress.
3. NASA should use five Common Themes to make the most efficient use of civil aeronautics R&T resources:
  - Physics-based analysis tools
  - Multidisciplinary design tools
  - Advanced configurations
  - Intelligent and adaptive systems
  - Complex interactive systems
4. NASA should support fundamental research to create the foundations for practical certification standards for new technologies.
5. The U.S. government should align organizational responsibilities as well as develop and implement techniques to improve change management for federal agencies and to assure a safe and cost-effective transition to the air transportation system of the future.
6. NASA should ensure that its civil aeronautics R&T plan features the substantive involvement of universities and industry, including a more balanced allocation of funding between in-house and external organizations than currently exists.
7. NASA should consult with non-NASA researchers to identify the most effective facilities and tools applicable to key aeronautics R&T projects and should facilitate collaborative research to ensure that each project has access to the most appropriate research capabilities, including test facilities; computational models and facilities; and intellectual capital, available from NASA, the Federal Aviation Administration, the Department of Defense, and other interested research organizations in government, industry, and academia.
8. The U.S. government should conduct a high-level review of organizational options for ensuring U.S. leadership in civil aeronautics.